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Impact of Christ's Thorn and Mango Trees on Sorghum (*Sorghum bicolor*) Yield in Parkland Agroforestry Practice at Harari Region, Ethiopia

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ABSTRACT

Understanding the nature of trees should provide an important step for improving the productivity of the components and designing agroforestry systems. The study was aimed to evaluate the impacts of parkland Christ's thorn and Mango trees species on the yield of sorghum within and outside the canopy of the tree in Harari Region Ethiopia. Accordingly, twelve trees (six for each) isolated and nearly similar Mango and Christ's thorn trees growing on more or less similar site conditions, management practices, canopy coverage and height were selected. Sorghum variety (bullo) which is dominantly grown around the study area was sown during rainy season along with existing both tree species in crop field. Three quadrates 1 m*1 m were laid out under, edge and outside the canopy of the trees in the sorghum farmland to assess the sorghum grain and biomass yield in parkland. The finding of the study also showed that the grain and biomass yield of sorghum were significantly ($P<0.05$) increased under canopy of Christ's thorn trees. Mango -sorghum interaction showed highly significant ($p<0.01$) reduction of sorghum biomass and grain yield under the tree canopy compared with open area. It can be concluded that the integration of trees particularly Mango with sorghum in parkland agroforestry should be promoted with effective tree crown management to reduce crop shading, particularly near the tree where the shading effect is high.

KEYWORDS: *Parkland agroforestry, grain yield, biomass yield, canopy cover, pruning*

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1. INTRODUCTION

Well-designed agroforestry practices can maximize the beneficial interactions among the system components, which could be possible through selection of trees and crops with best-matching patterns in light, water and nutrient acquisition (Agena, 2009). Different studies on soil-trees-crop relation in agroforestry practices showed that selected trees and shrubs improve soil fertility which results in boosting crop yield (Zerfu *et al.,* 2020). However, all trees on the farm cannot improve soil property and crop yield; some trees negatively affect the yield and growth of associated annual crop. For instance, Mesfin *et al.* (2014) found significant depression of maize yields within first 1 m distance from the Avocado trees line resulting in the reduction of 96.5% and 89.8% for grain and biomass, respectively as compared to outside of canopy. The effect of trees on annual crop productivity is also based on the cumulative effect of both above and below-ground component interaction (Muktar *et al.*, 2018). Therefore, investigation of the biophysical interactions of trees and crops under different ecological settings is vital to properly managing farm trees or sustaining the system.

Scattered *Mango* and Christ's thorn trees on sorghum field are common practice in the Harari Region and thus, information on their biophysical interaction need to be assessed to manage the system properly and enhance its productivity. In particular, empirical evidence is required to demonstrate the effects of trees on yield of crops to convince land users and policy makers to promote the integration of trees in

farming systems. Therefore, this study investigated the effect of parkland Christ's thorn and *Mango* trees on yield of sorghum under and outside the tree canopy as compared to the control on open sites. The results will be useful to farmers and other stakeholders to give insight into the effects of parkland trees on sorghum yield in their farmlands. The information can also help in designing sustainable land use that could enhance the productivity of crops while maintaining and improving the resource base. The objective of this study was to evaluate the effect of Christ's thorn and *Mango* trees on grain and biomass yield of sorghum at different distance from the trees trunk in parkland agroforestry practice in Harari Region, Eastern Ethiopia

2. MATERIALS AND METHODS

2.1. Description of the study Area

This research was conducted in Sofi District, Harari Region, Ethiopia. The study area is located longitude with an elevation range of 1300–1600 m.a.s.l. The mean minimum and maximum annual air temperatures of the area are 15 °C and 31 °C, respectively. The district has a bimodal rainfall distribution pattern with erratic rain from April to June and long and main rain from July to September. The district has two basic agro-climatic conditions, *i.e*. 20% of the land area of the district is midland (*weyna dega*), while the remaining 80% is lowland or *kola*. In the Sofi District medium textured sandy clay loam and sandy loam is dominant and rated as slightly to moderate alkaline with good permeability soils. Crops cultivation with multipurpose trees (MPT) and/or livestock) are the major means of livelihood in the area. Sorghum is the dominant crop grown in the area followed by groundnut (*Arachis hypogaea L.*), maize (*Zea mays* L.), and haricot beans (*Phaseolus vulgaris*). Scattered MPT species grown in annual crops field is also the most common AF practices in the area.

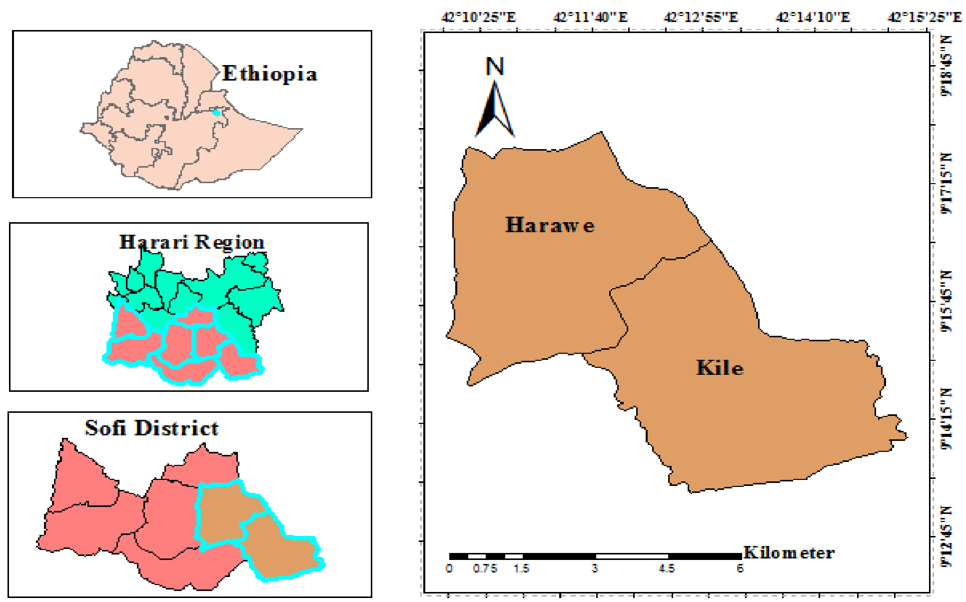

Figure 1. Location map of the study area (Kile and Harawe kebeles of Sofi District).

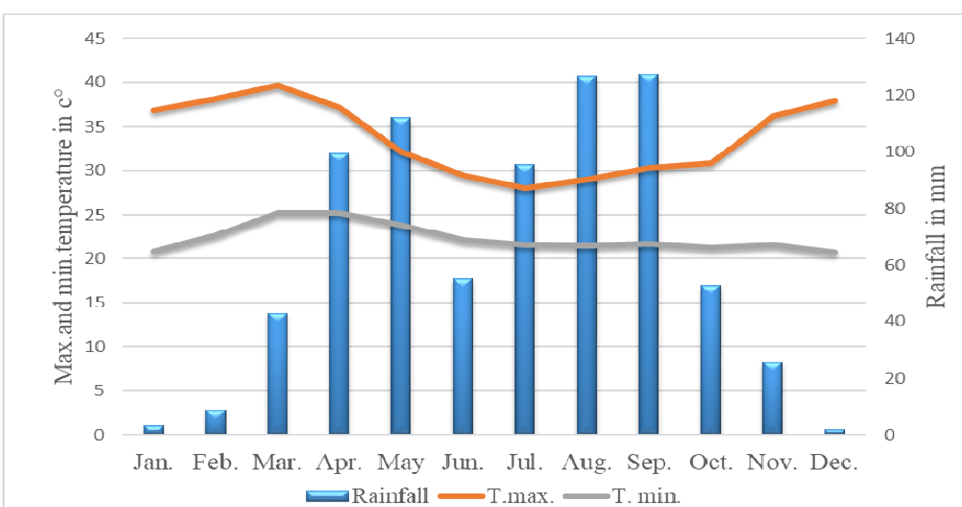

Figure 2. Average monthly rainfall (mm), maximum and minimum temperature (^{0}C) of the study area for the period 2013-2022 E.C.

The study was carried out on farmers' farmlands in Sofi District, Harari Region to compare the selected soil physical and chemical properties under traditionally retained and deliberately planted parkland Christ's thorn and *Mango* trees against the open field (outside the canopy cover). The trees being the most abundant scattered tree species on sorghum fields were selected for this study. Based on the potential existing of parkland agroforestry practices Sofi district was selected from Harari Regional State. Then two rural kebeles, namely Kile and Harawe were purposively selected based on the potential existence of the selected tree species on farmland with sorghum production.

2.2. Sampling of Christ's thorn and Mango Trees in Sorghum Farm land

Two tree species *(*Christ's thorn and *Mango)* were purposively selected because they are dominantly grown tree species along with sorghum and were already adapted in the study area. Six isolated and nearly identical individual Christ's thorn *and* Mango have approximately similar canopy width, management history, age, height, diameter at breast height (DBH), slope similarity and absence of influence from other types of trees species grown on the sorghum field were selected from the target study sites. The twelve trees (six for both tree species) were considered as replications. The height, DBH and crown diameter of the trees were measured by using clinometer, caliper and meter tape, respectively. The dimension of each replication was almost uniform with the average DBH, height, and crown diameter of 51.58 cm, 10.53 m and 11.11 m for *Mango*, respectively. Similarly, for Christ's thorn the average DBH, height and crown diameter were 42 cm, 10.76 m and 9.33 m, respectively.

2.3. Grain and Above Ground Biomass Yield of Sorghum

Sorghum was sown during the rainy season along with existing tree species (*Mango* and Christ's thorn) in farmland as parkland agroforestry practices at both selected kebeles of the district. Sorghum was sown under and out of the canopy of selected tree species, which have almost the same age, height and management practices. Relatively homogenous soil type, site conditions in terms of slope, aspect and topography and growth and vigor of the trees were also considered in the selection of the trees of each species. Seeds of sorghum were sown during rainy season on farmers managed cropland by hand drilling with national recommendation rate (12 kg ha^{-1}) and spacing (75 cm between row and 20 cm between plants) of sorghum. NPS fertilizer was applied at the rate of 100 kg ha^{-1} during planting and urea was applied as top dressing of 50 kg ha^{-1} at knee height stage uniformly under, edge and outside of canopy of the trees in all experiments sites of parkland agroforestry. Weeding and other management practices were applied as per recommended for the site.

The sorghum variety used for this study was local variety *(bullo)* which is dominantly grown by farmers and already adapted around the study area. For sorghum experiment there was only- one factor involved in this study; distance from the tree trunk under both selected tree species. The distance factor had three different treatment levels; under canopy, edge of canopy and outside the canopy (10 m) as control which replicate 6 times; 3*6 and 36 total sample units or sample size for sorghum yield were used in this study for both tree species. Three quadrate 1 m * 1 m were laid on the existing sorghum farm under the canopy of the trees, edge of the canopy and outside the canopy of the tree. Three plots were laid in four directions (North, South, East and West) under selected trees on the existing sorghum farm field for assessing the sorghum yield on the farmer managed farm field. Sorghum was harvested manually from each plot and data were collected from all plants grown in the plots. Biomass yield was measured weight of the above ground plant parts harvested from all plants in the plots after dried for ten days in open sun. Grain yield of sorghum were measured by harvesting from all plants in the net quadrate of 1 m^2, sun-dried, trashed manually, cleaned and weighted using digital balance and converted yield per plot to yield in kg ha^{-1} for both grain and above ground biomass.

2.4. Method of Data Analysis

The statistical differences between the values for the various parameters of sorghum grain and biomass yield were subjected to analysis of variance following the General Linear Model (GLM) procedure of Statistical Analysis System (SAS) version 9.2 (SAS, 2008). The Duncan's Multiple Range Test (DMRT) was used to separate significantly differing treatment means following the main effects were to be curtained to significantly different ($P < 0.05$).

3. RESULTS AND DISCUSSION

3.1. Effect of Christ's thorn Trees on Grain and Above Ground Biomass Yield of Sorghum in Parkland Agroforestry

The analysis of variance showed that the grain and biomass yields of sorghum were significantly different ($P<0.05$) across the distance from the Christ's thorn in farmland (Table 1). The mean values of grain and biomass yield of sorghum decreased significantly with increasing distance from the Christ's thorn trees in the sorghum field. Accordingly, the overall mean values of above-ground biomass and grain yield of sorghum were higher at

the canopy zone of Christ's thorn than in the open field. Increased grain and biomass yield under the canopy of Christ's thorn, trees by 17% and 30.3% respectively than the outside canopy of trees (Table 1).

Table 1. The effect of Christ's thorn on sorghum grain and biomass yield (kg/ha) at different distances from trees trunk

Distance from the tree trunk	Grain yield (kg/ha)	Above ground Biomass yield (kg/ha)
Under canopy	1778.2[a]	7316.7[a]
Edge of canopy	1636.1[ab]	6618.2[ab]
Out of canopy(10m)	1459.2[b]	5345.9[b]
LSD (5%)	242.87	1546.6

* Means with the same letter are not significantly different (P< 0.05)

The increase in grain and above-ground biomass yield under the trees could be due to the phenological characteristics of the tree species; partial canopy cover, which allows more light for photosynthesis reaction and improvement of soil properties, and under the tree canopies than the open fields. This yield increase may result from:(1) light shading early in the cropping season, which results in a decrease in soil surface temperatures and reduce moisture loss (2) nutrients assimilated through the roots are returned to the soil surface through litter fall; and (3) feces and urine deposition by cattle seeking shade and fodder during the dry season. Hadgu *et al*. (2009) reported similar findings under the *A. albida* tree.

Moreover, the finding of the study implies that even non-nitrogen fixing trees (Mango and Christ's thorn) release organic matter and thereby, improve the physicochemical properties of soil in parkland agroforestry practice which could increase crop yield. In line with this current result, Desta (2018) also reported that crops grown under the canopy of *Acacia tortilis* obtained more advantages compared to the open field in the Central Rift Valley of Ethiopia. The mean variation at three distances (under, edge, and out of the canopy of trees) might come from modification of microclimate and soil physical and chemical properties by the tree species. The grain and biomass yield of sorghum decreased significantly and gradually as the distance from the tree trunk increased in parkland agroforestry in Kersa District, East Hararghe zone (Sisay, 2021), which is similar to the present study.

Contrary to the current study finding, sorghum height, grain, and biomass yields were not significantly different among the three distances; under the canopy, near the canopy, and far from the canopy (10 m) of *B. aegyptica* in sorghum farmland (Hailemariam *et al*., 2010). Haile *et al. (*2019) also reported that the grain and biomass yield of sorghum gradually decreased as the distance from trees increase due to soils under *Z.spina-christi* tree canopies being more fertile than the outside from higher accumulation of soil organic matter. Moreover, the current result is in agreement with, Alemayewu *et al*. (2017) higher sorghum yield under the canopy of *A. senegal* than out of the canopy (open field). This may be attributed to the improved soil fertility and modified microclimate parameters under the canopy than the outside canopy. Improved the grain yields by 12.1% and 14.5% under the canopy zone of *Z. spina-christi* for wheat and maize by increasing respective yield components (Yang *et al*., 2016).

3.2. Effect of Mango Trees on Grain and Above Ground Biomass Yield of Sorghum in Parkland Agroforestry

Sorghum aboveground biomass and grain yield were found highly significantly ($P \leq 0.01$) affected by the presence of *Mango* trees in sorghum farmland (Table 2). Above-ground biomass and grain yield of sorghum were lower under the canopy as compared to the edge of the canopy and out of the canopy of trees. Biomass and grain yield was reduced by amount 34.15% and 56.58% under a canopy of *Mango* as compared to an open field. Accordingly, the mean values of grain and biomass yield of sorghum increased significantly with increasing distance from the *Mango* trees in the sorghum field (Table 2).

Table 2. The effect of *Mango* on sorghum grain and biomass yield (kg/ha) at different distances from trees trunk

Distance from the trunk of the trees	Grain yield (kg/ha)	Above ground biomass yield (kg/ha)
Under canopy	685.91[c]	2345.5[c]
Edge of canopy	1013.63[b]	3557.2[b]
Out of canopy(10m)	1563.39[a]	5402.5[a]
LSD (5%)	167.14	936.46

* Means with the same letter are not significantly different (P< 0.05)

The decrease in grain and biomass yield under the trees may be due to the large and dense canopy cover of the trees and high competition for light under the tree canopies. This might be due to the shading effect of the trees on seed emergence and seedling survival. Additionally, farmers around the study area never prune branches of scattered *Mango* trees grown in crop fields even if it affects the production of annual crops. It might also be due to the shade intolerance character of sorghum (Hassan *et al*., 2018). Mango has heavy shade or canopy, its leaves are evergreen and not shade its leaves during crop growing season, which allows light competition for photosynthesis reaction. However, soils under tree canopies were more fertile than the outside due to a higher accumulation of soil organic matter.

Generally, the result showed increases in biomass and grain yield of sorghum with increasing distances from a mango tree trunk in farmland. Thus, deliberate integration and intensive management of *the* trees in the agricultural system are vital for obtaining the desired optimum benefit from the practice. In line with this current result, in avocado and maize interaction, both maize yield and biomass showed increasing trends with increasing radial distance from trunk and light affect competition affect maize yield under the avocado canopy in southern Ethiopia (Mesfin *et al*., 2014). Severe impacts of trees on agricultural productivity are often location specific; tree species depend on and greatly vary with tree-crop configuration and management (Sileshi, 2016).

Crops (finger millet, niger, groundnut, Fenugreeks, chilly, and bean) achieved maximum profit hence, it is recommended such types of crops be planted as an intercrop in mango plantation during the main rainy season (Meshram *et al*., 2020). The authors suggest that proper crown management is necessary for agroforestry systems. Contrary to the current finding, Tiwari and Baghel(2014) recommended growing mango under rain-fed with annual crops like maize, sorghum, beans, groundnut, etc., vegetables, and perennial cash crop. The study by Kar (2012) also concludes that inter cropping of onion in mango trees has the highest return value and the yield of tomato is highest by growing under *Mango* with canopy management of trees. Moreover, the current result also disagreed with the highest biomass and grain yield of sorghum reported under the *F. albida and Cordia africana* canopy than the outside canopy at Fadis district, Ethiopia without any crown management of trees (Musa, 2020).

4. CONCLUSIONS & RECOMMENDATIONS

Mango and Christ's thorn trees are dominantly grown along with sorghum and managed in the form of parkland agroforestry practices in Sofi district, Harari Region, Ethiopia. However, the effect of these trees species on sorghum yield was not scientifically studied in the area. Information can help to promote agroforestry trees on farmland, manage the system or components properly and enhance their productivity. The twelve trees (six for each) isolated and approximately similar individual Christ's thorn *and* Mango trees were selected from the study sites. Sorghum was sown under and out of the canopy of selected trees species with continuous follow-up and management practices during the whole growing period. Quadrate 1 m * 1 m were laid on the crop field under, edge and outside of the canopy (10m from the trees) to assess sorghum yield. Grain and biomass yield data of sorghum were collected by harvesting from all plants in the net quadrate.

The result of the study revealed that the grain yield of sorghum was increased under a canopy of Christ's thorn, due to the partial canopy cover of trees, which allows more light for photosynthesis reaction and improvement of soil properties under the tree canopies than the open fields. However, sorghum yield is reduced under the canopy of *Mango* because of the large and dense canopy cover of the trees which may cause light competition and affect sorghum seeds' emergence and seedling survival; which require tree crown management. However, both *Mango* and Christ's thorn trees species had improved selected soil physicochemical properties in parkland agroforestry practice in the study site. Therefore, parkland agroforestry practices involving *Mango* and Christ's thorn can be used as an economically feasible, environmentally friendly, and sustainable alternative to maintaining soil fertility to resource-poor farmers in similar agro ecological conditions. Based on the findings, the research induces the following recommendations: The integration of *Mango* with sorghum in parkland agroforestry practice should be promoted with effective tree crown management to reduce the canopy shading on crops which affects the production yield of the sorghum. Furthermore, research is required on the impacts of trees pruning and other silvicultural management practices on the yield and yield components of the understory crops and offer the findings to the policymakers to enhance the parkland agroforestry practice.

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